

Optimal monetary policy under menu costs

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The views expressed are my own and do not necessarily reflect those of the OFR or the Department of Treasury.

Suppose prices are sticky. What should central banks do?

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Textbook benchmark: Tractable-but-unrealistic **Calvo friction**

- *Random and exogenous* price stickiness

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Woodford 2003; Rubbo 2023

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Criticism:

- Theoretical critique: Not microfounded
- Empirical critique: State-dependent pricing is a better fit

► [examples](#)

Nakamura et al 2018; Cavallo and Rigobon 2016; Alvarez et al 2018; Cavallo et al 2023

Optimal policy under menu costs

Our contribution: More realistic (less tractable) menu costs

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 - ⇒ Motive for relative prices to change

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- **Stylized analytical model**
- **Quantitative model**

Related literature

- Optimal monetary policy with sectors / relative prices, Calvo

Aoki 2001, Woodford 2003, Benigno 2004, Wolman 2011, Rubbo 2023

- Menu costs *assuming* inflation targeting, solve for optimal inflation target

Wolman 2011, Nakov-Thomas 2014, Blanco 2021

- Menu costs + trending productivities (no direct costs)

Adam and Weber 2023

- Optimal policy with menu costs w/out sectors

Karadi, Nakov, Nuno, Pasten, and Thaler 2024

- Non-normative menu cost literature

- * Theoretical

Golosov-Lucas 2007; Caballero-Engel 2007; Nakamura-Steinsson 2009;

Alvarez-Lippi-Paciello 2011; Midrigan 2011; Gertler-Leahy 2008; Auclert et al 2023

- * Empirical

Nakamura et al 2018; Cavallo-Rigobon 2016; Alvarez et al 2018; Gautier-Le Bihan 2022

Roadmap

1. **Baseline model & optimal policy**
2. **Extensions**
3. **Comparison to Calvo model**
4. **Quantitative model**
5. **Conclusion and bigger picture**

Model setup + household's problem

General setup:

- Off-the shelf sectoral model with S sectors
- Each sector is a continuum of firms, bundled with CES technology
- Static model (& no linear approximation)

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$$\begin{aligned} \max_{C, N, M} \quad & \ln(C) - N + \ln\left(\frac{M}{P}\right) \\ \text{s.t.} \quad & PC + M = WN + D + M_{-1} - T \\ & C = \prod_{i=1}^S c_i^{1/S} \end{aligned}$$

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Optimality conditions:

$$\begin{aligned} c_i &= \frac{1}{S} \frac{PC}{p_i} \\ PC &= M \\ W &= M \end{aligned}$$

Intermediate firms: price setting with menu costs

Technology: firm $j \in [0, 1]$ in sector i

$$y_i(j) = A_i \cdot n_i(j)$$

Demand: $y_i(j) = y_i \left(\frac{p_i(j)}{p_i} \right)^{-\eta}$

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Profit function:

$$\left(p_i y_i - \frac{W}{A_i} y_i (1 - \tau) \right) - W \psi \chi_i$$

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Menu cost: ψ extra units of labor

- χ_i : indicator for price change

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\implies **Direct cost of menu costs:** excess disutility of labor

$$N = \sum_i n_i + \psi \sum_i \chi_i$$

- Other specifications do not affect result ▶ more

Menu costs induce an inaction region

Objective function of sector i firm: $\left(p_i y_i - \frac{W}{A_i} y_i (1 - \tau) \right) - W \psi \chi_i$

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- if adjusting: **price = nominal marginal cost**

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- if not adjusting: inherited price p_i^{old}

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Inaction region: don't adjust iff $p_i^* = \frac{W}{A_i}$ close to p_i^{old}

Optimal policy after a productivity shock

► Formal planner's problem

- Start at steady state: all sectors have $A_i^{ss} = 1 \quad \forall i$, so $p_i^{ss} = W^{ss} \equiv 1$

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Proposition 1: there exists a threshold level of productivity \bar{A} s.t.:

- If shock is not too small, $A_1 \geq \bar{A}$, optimal policy is nominal wage targeting:

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- If shock is small, $A_1 < \bar{A}$, then optimal policy ensures no sector adjusts:

$$p_i = p_i^{ss} \quad \forall i$$

Large-enough shocks

$$\text{Recall: } p_i^* = MC_i = \frac{W}{A_i}$$



Large-enough shocks

- Sector 1 productivity $A_1 \uparrow$
 \implies relative price p_1/p_k should fall

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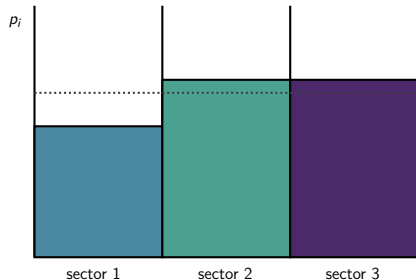
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Inflation targeting

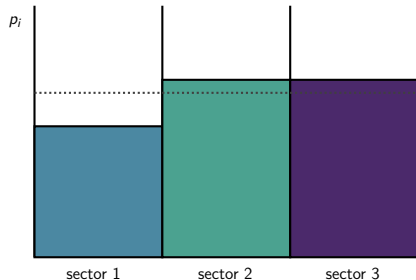
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Inflation targeting

$$W^f - S\psi$$

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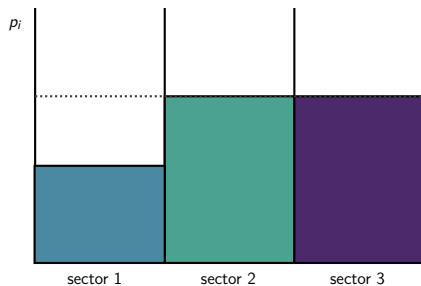
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- * $p_1 \downarrow$, but p_k **constant**

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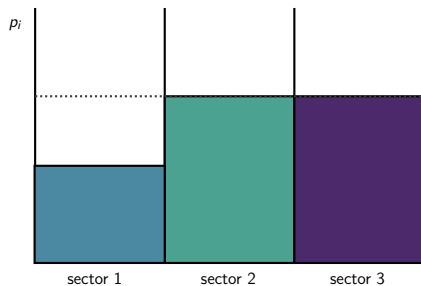
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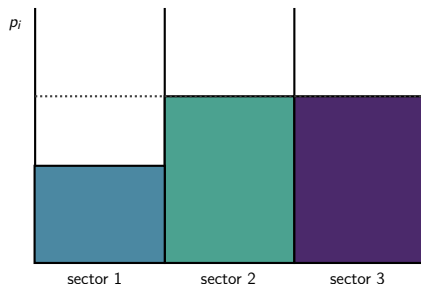
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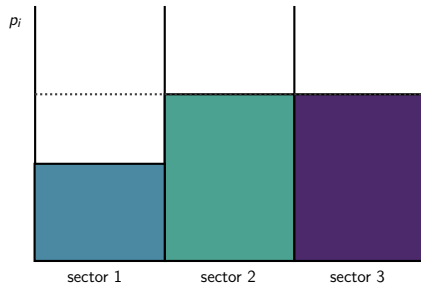
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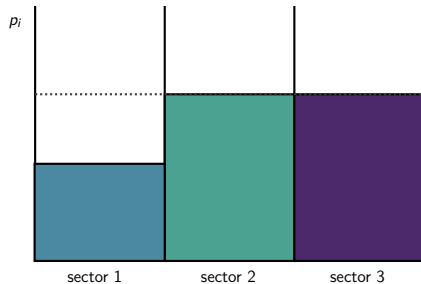
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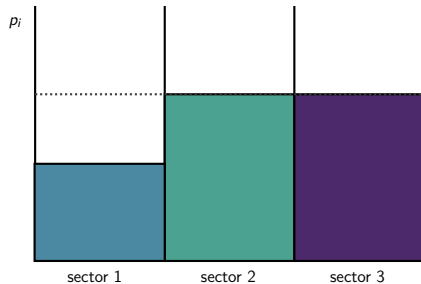
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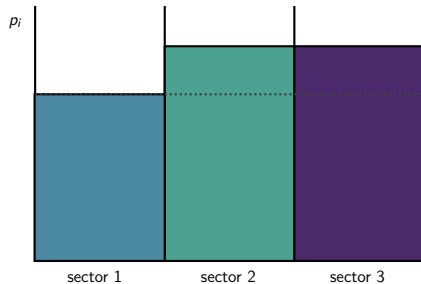
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Only sectors k adjusts
 $W^f - (S-1)\psi$

Small shocks: state dependent optimal policy

► math

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Sector 1 adjusts		
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Lemma 2: $\exists \bar{A}$ such that

$$\mathbb{W}_{\text{only 1 adjusts}} > \mathbb{W}_{\text{none adjust}}$$

iff $A_1 > \bar{A}$. Furthermore, \bar{A} is increasing in ψ .

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- (1) Measure *frequency of price adjustment*
- (2) Build structural model
- (3) \implies *calibrate* menu costs to fit

Nakamura and Steinsson (2010):

- 0.5% of firm revenues

Blanco et al (2022):

- 2.4% of revenues

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2. Direct measurement. For *physical* adjustment costs,

Levy et al (1997, QJE): 5 grocery chains

- 0.7% revenue

Dutta et al (1999, JMCB): drugstores

- 0.6% revenue

Zbaracki et al (2003, Restat): mfg

- 1.2% revenue

Extensions

- Generalized functional forms
- Multiple shocks / production networks
- Heterogenous costs
- Sticky wages

► more

Generalization: stabilize nominal MC of unshocked firms

Generalized model:

- Any (HOD1) aggregator:

$$C = F(c_1, \dots, c_S)$$

- DRS production technology:

$$y_i(j) = A_i n_i(j)^\alpha, \alpha \in (0, 1]$$

- Any preferences quasilinear in labor:

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Nominal MC:

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Extended Proposition 1:

Stabilize **nominal marginal costs of unshocked firms** $\implies Y \uparrow, P \downarrow$

Production networks

Baseline model:

- Production technology:

$$y_i = A_i n_i$$

Roundabout production network:

- Production technology:

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$$l_i = \prod_{k=1}^S l_i(k)^{1/S}$$

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 $\equiv W^\beta P^{1-\beta}$

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$$\psi \cdot \mathbb{I}\{p_i \neq p_i^{ss}\}$$

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- **Menu costs are *nonconvex*:**

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- **With *convex* menu costs:**

e.g. Rotemberg, $\psi \cdot (p_i - p_i^{ss})^2$

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$$N = \sum n_i + \psi \sum \mathbb{I}\{p_i \neq p_i^{ss}\}$$

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- **Calvo:** *convex* cost of price dispersion

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- Calvo welfare cost

$$\Delta \equiv \sum_{i=1}^S \int_0^1 \left[\frac{p_i(j)}{p_i} \right]^{-\eta} dj$$

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$$\psi \cdot \mathbb{I}\{p_i \neq p_i^{ss}\}$$

- With **convex** menu costs:

$$\text{e.g. Rotemberg, } \psi \cdot (p_i - p_i^{ss})^2$$

- **Calvo**: *convex* cost of price dispersion

- Labor market clearing:

$$N = \sum n_i + \psi \sum \mathbb{I}\{p_i \neq p_i^{ss}\}$$

- Labor market clearing:

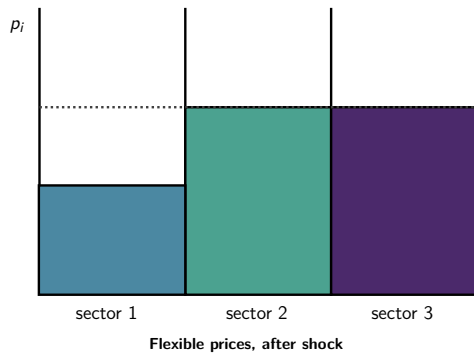
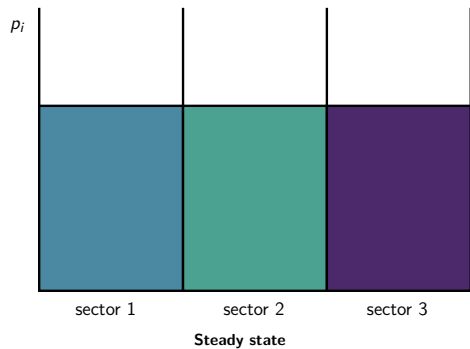
$$N = \sum n_i + \psi \sum (p_i - p_i^{ss})^2$$

- Calvo welfare cost

$$\Delta \equiv \sum_{i=1}^S \int_0^1 \left[\frac{p_i(j)}{p_i} \right]^{-\eta} dj$$

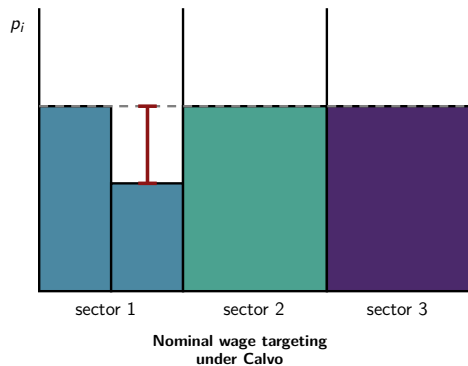
Convex costs \implies smooth price changes across sectors

Calvo diagram: shocking sector-1 productivity



Calvo diagram: shocking sector-1 productivity

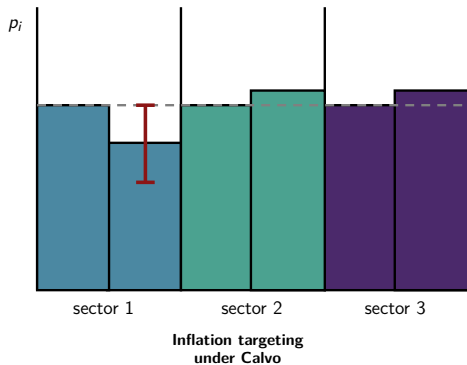
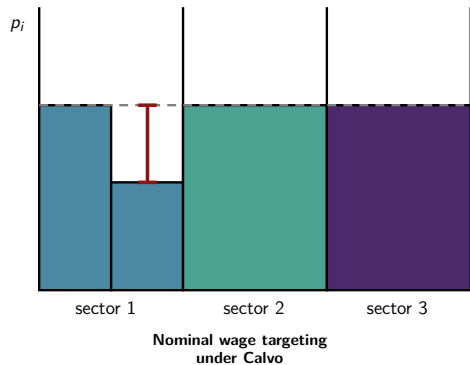
► math



Lots of price dispersion: only one sector

Calvo diagram: shocking sector-1 productivity

► math

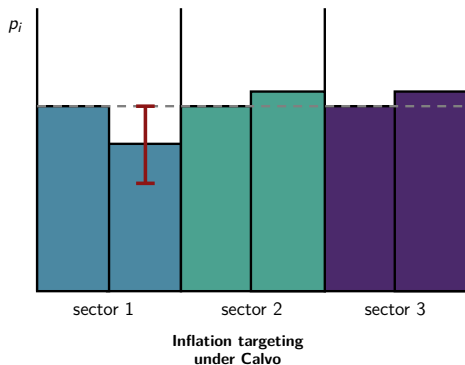
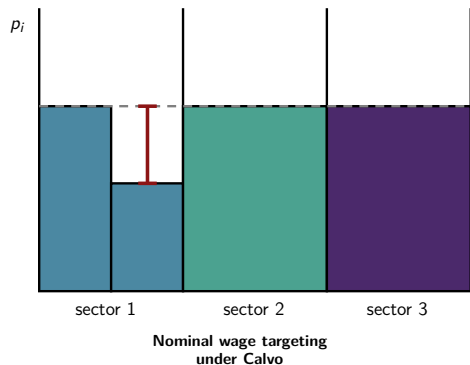


Lots of price dispersion: only one sector

Little price dispersion: all sectors

Calvo diagram: shocking sector-1 productivity

► math



Lots of price dispersion: only one sector

Little price dispersion: all sectors

Convex costs \implies smooth price changes across sectors

Quantitative model: setup

Dynamic model, **idiosyncratic** + sectoral shocks, and **Calvo plus** price setting

Household

$$\begin{aligned} & \max_{\{C_t, N_t, B_t, M_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\gamma}}{1-\gamma} - \omega \frac{N_t^{1+\varphi}}{1+\varphi} + \ln \left(\frac{M_t}{P_t} \right) \right] \\ \text{s.t.} \quad & P_t C_t + B_t + M_t \leq R_t B_{t-1} + W_t N_t + M_{t-1} + D_t - T_t \end{aligned}$$

Firms

- * final and sectoral good producers: same as in static model

Quantitative model: intermediate firms

Intermediate firms: **idiosyncratic** shocks, **Calvo+** price setting

$$\begin{aligned} \max_{p_{it}(j), \chi_{it}(j)} \quad & \sum_{t=0}^{\infty} \mathbb{E} \left[\frac{1}{R^t P_t} \{ p_{it}(j) y_{it}(j) - W_t n_{it}(j) (1 - \tau) - \chi_{it}(j) \psi W_t \} \right] \\ \text{s.t.} \quad & y_{it}(j) = A_{it} a_{it}(j) n_{it}(j)^{\alpha} \\ & \psi_{it}(j) = \begin{cases} \psi & \text{w/ prob. } 1 - \nu \\ 0 & \text{otherwise} \end{cases} \end{aligned}$$

productivity distribution is mixture between AR(1) and uniform (**fat tail**)

$$\log(a_{it}(j)) = \begin{cases} \rho_{\text{idio}} \log(a_{it-1}(j)) + \varepsilon_{it}^{\text{idio}}(j) & \text{with prob. } 1 - \varsigma \\ \mathcal{U}[-\log(\underline{a}), \log(\bar{a})] & \text{with prob. } \varsigma \end{cases}$$

Calibration

Two sets of parameters to calibrate:

(1) standard or drawn from literature and

	Parameter (monthly frequency)	Value	Target
β	Discount factor	0.99835	2% annual interest rate
ω	Disutility of labor	1	standard
φ	Inverse Frisch elasticity	0	Golosov and Lucas (2007)
γ	Inverse EIS	2	standard
S	Number of sectors	6	Nakamura and Steinsson (2010)
η	Elasticity of subst. between sectors	5	standard value
α	Returns to scale	0.6	standard value
τ	Labor subsidy	0.2	$1/\eta$

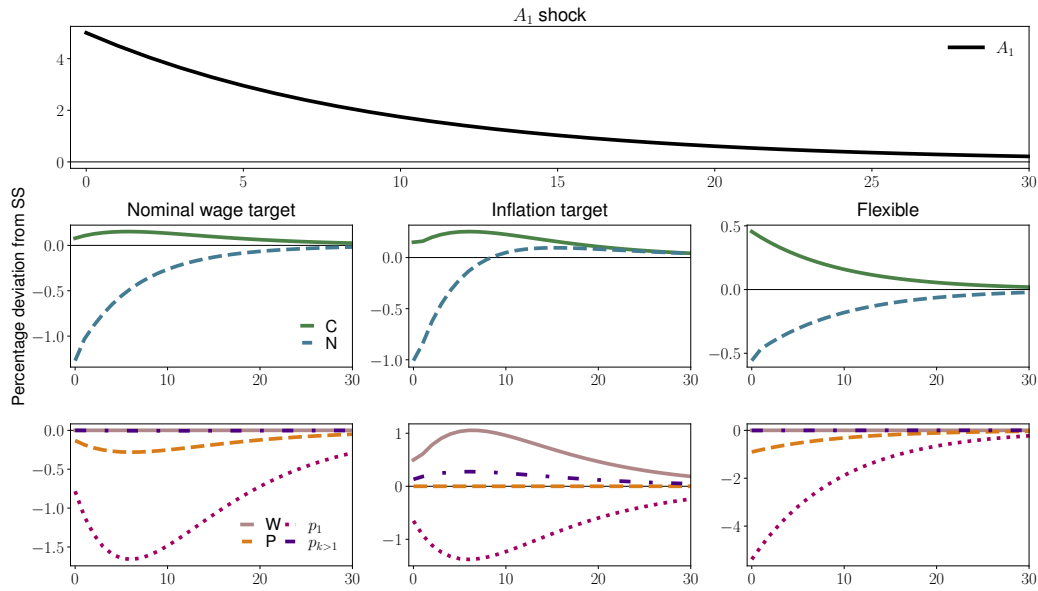
Calibration

Two sets of parameters to calibrate:

(1) standard or drawn from literature and (2) calibrated by **SMM** targeting

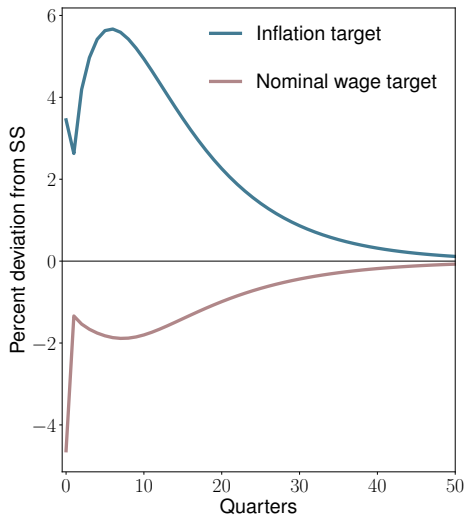
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τ	Labor subsidy	0.2	$1/\eta$
σ_{idio}	Standard deviation of idio. shocks	0.044	menu cost expenditure / revenue 1%(1.1%)
ρ_{idio}	Persistence of idio. shocks	0.995	share of price changers 8.7% (8.3%)
ψ	Menu cost	0.1	median absolute price change 8.5% (8.7%)
ν	Calvo parameter	0.075	Q1 absolute price change 4.5% (4.2%)
ζ	Fat tail parameter	0.0016	Q3 absolute price change 20.4% (14.8%)
			kurtosis of price changes 3.609 (2.755)

Exercise: perfect foresight sectoral shock

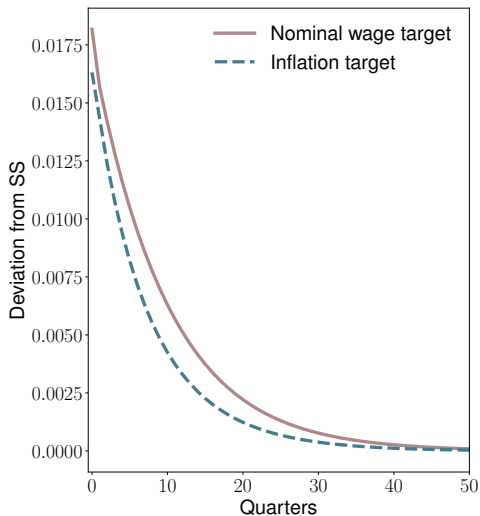


Policy comparison: menu costs and welfare

Real menu cost expenditure

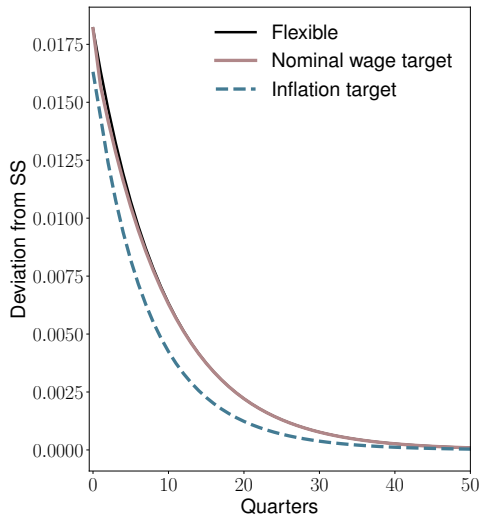


Welfare



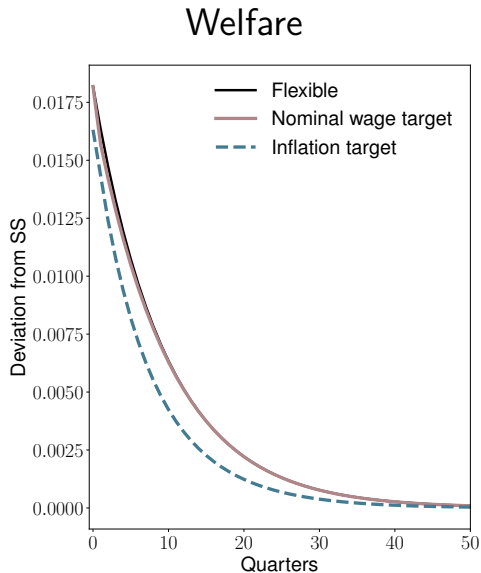
Policy comparison: consumption equivalence

Welfare



Policy comparison: consumption equivalence

- Consider **welfare** under W targeting



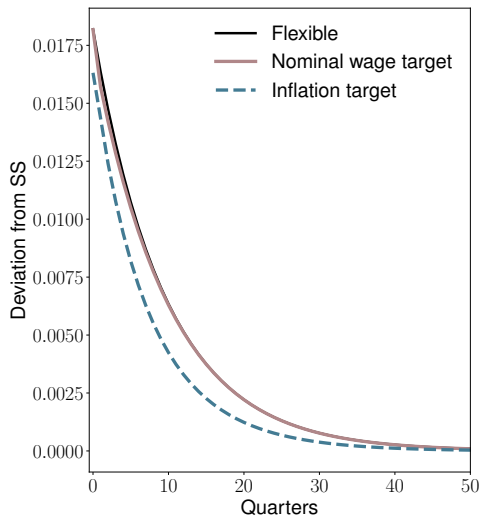
Policy comparison: consumption equivalence

- Consider welfare under W targeting
- Extra C needed to match welfare under flexible prices

$$\begin{aligned} & \sum_t \beta^t U((1 + \lambda) C_t, N_t) \\ &= \sum_t \beta^t U(C_t^{\text{flex}}, N_t^{\text{flex}}) \end{aligned}$$

- $\lambda^W = 0.002\%$ $\lambda^P = 0.025\%$

Welfare



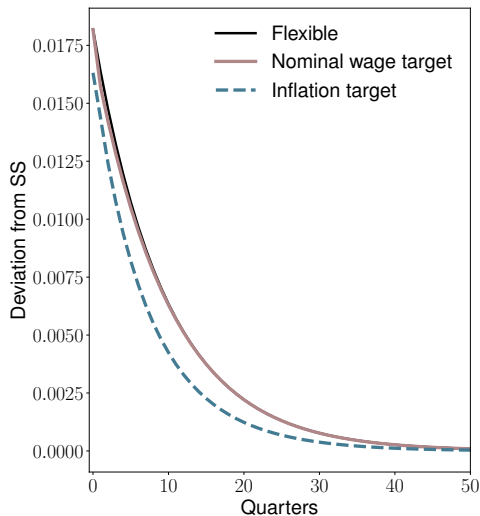
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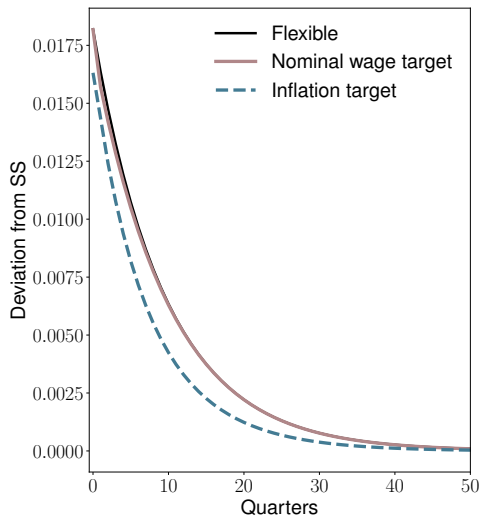
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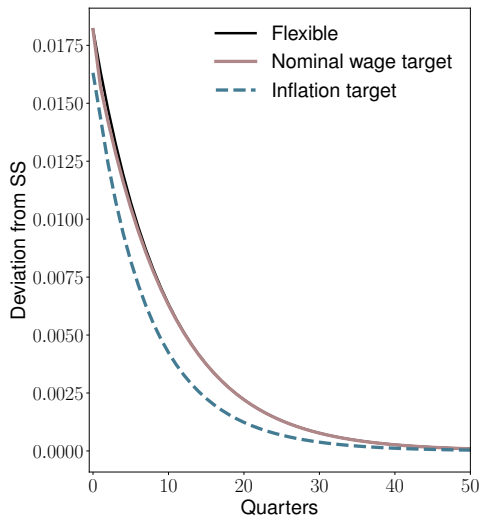
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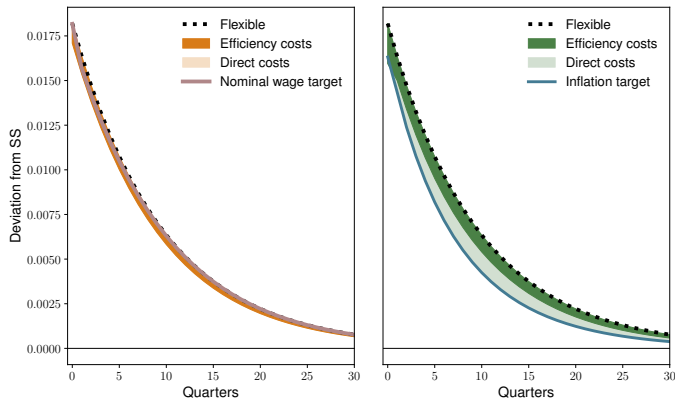
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Welfare



Decomposing welfare

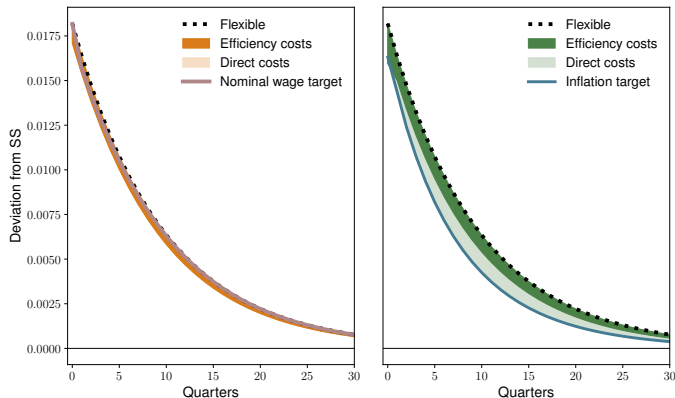
Welfare response to A_1 shock



1. **Direct costs:** $\psi\chi_t$, disutility of labor from menu costs
2. **Efficiency costs:** welfare loss from incorrect relative prices

Decomposing welfare

Welfare response to A_1 shock



1. **Direct costs:** $\psi\chi_t$, disutility of labor from menu costs

2. **Efficiency costs:** welfare loss from incorrect relative prices

- Direct costs:
 $\tilde{\lambda}^W = 0.008\%$ and
 $\tilde{\lambda}^P = 0.013\%$
- **Interpretation:** improvement from both channels

Welfare over the business cycle

- Shock sector productivities according to

$$\log(A_t) = \rho_A \log(A_{t-1}) + \varepsilon_A$$

- $\rho_A = 0.95$ $\sigma_A \sim \mathcal{N}(0, 0.0161)$

Garin, Pries, and Sims (2018)

- Consumption equivalence results:

- * $\lambda^P = 0.01$ versus $\lambda^W = 0.003$

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Garin, Pries, and Sims (2018)

- Consumption equivalence results:

- * $\lambda^P = 0.01$ versus $\lambda^W = 0.003$

⇒ Nominal wage targeting dominates inflation targeting in quantitative model

Conclusion

Inflation should be countercyclical after sectoral shocks

Rationale:

- Inflation targeting **forces firms to adjust unnecessarily**, which is costly
- Nominal wage targeting does not and still achieves “correct” relative prices

This aligns with the implications of other recent work:

- Calvo sticky wages
- Incomplete markets/financial frictions: Sheedy (2014), Werning (2014)
- Information frictions: Angeletos and La'O (2020)
- Sticky prices [**new**]: **Caratelli and Halperin (2024)**

Thank you!

Formally: Social planner's problem

► back

$$\max_{X \in \{A, B, C, D\}} \mathbb{U}^X$$

$$\mathbb{U}^A = \left\{ \begin{array}{ll} \max & M \ln[M] - M[S - 1 + 1/\gamma] \\ \text{s.t.} & \min(\gamma\lambda_1, \lambda_2) \leq M \leq \max(\gamma\lambda_1, \lambda_2) \end{array} \right\}$$

$$\mathbb{U}^B = \left\{ \ln \left[\frac{1}{S} \gamma^{1/S} \right] - 1 - \psi \right\}$$

$$\mathbb{U}^C = \left\{ \begin{array}{ll} \max & M \ln \left[\left(\frac{\gamma}{S} \right)^{\frac{1}{S}} \cdot M^{\frac{S-1}{S}} \right] - \left[(S-1)M + \frac{1}{S} \right] - \frac{1}{S} \psi \\ \text{s.t.} & \lambda_1 < M < \min(\gamma\lambda_1, \lambda_2) \end{array} \right\}$$

$$\mathbb{U}^D = \left\{ \begin{array}{ll} \max & M \ln \left[S^{\frac{1-S}{S}} M^{\frac{1}{S}} \right] - \left[\frac{S-1}{S} + \frac{M}{\gamma} \right] - \frac{S-1}{S} \psi \\ \text{s.t.} & \max(\gamma\lambda_1, \lambda_2) < M < \gamma\lambda_2 \end{array} \right\}$$

$$\text{where } \lambda_1 = \frac{1}{S} (1 - \sqrt{\psi}), \quad \lambda_2 = \frac{1}{S} (1 + \sqrt{\psi})$$

Adjustment externalities

► back

Example: Social planner's *constrained* problem for “neither adjust”

$$\max_M U(C(M), N(M)) \quad (1)$$

$$\text{s.t. } D_1^{\text{adjust}} < D_1^{\text{no adjust}} \quad (2)$$

$$D_k^{\text{adjust}} < D_k^{\text{no adjust}} \quad (3)$$

$$\implies M_{\text{unconstrained}}^*$$

Social planner's *unconstrained* problem: maximize (1), without constraints

$$\implies M_{\text{constrained}}^*$$

Adjustment externality: $M_{\text{unconstrained}}^* \neq M_{\text{constrained}}^*$

Alternative menu cost formulations

► back

Labor costs: Welfare mechanism is *higher labor*

$$\begin{aligned} & \text{profits}_i - W\psi \cdot \chi_i \\ \implies N &= \sum n_i + \psi \sum \chi_i \end{aligned}$$

Real resource cost: Welfare mechanism is *lower consumption*

$$\begin{aligned} & \text{profits}_i \cdot (1 - \psi \cdot \chi_i) \\ \implies C &= Y \left(1 - \psi \sum_i \chi_i \right) \end{aligned}$$

Direct utility cost: Welfare mechanism is *direct*

$$\text{utility} - \psi \cdot \sum \chi_i$$

Heterogeneity: “least-cost avoider principle”

► back

Proposition 5: Suppose sector i has mass S_i and menu cost ψ_i . Suppose further

$$S_1\psi_1 < \sum_{k>1} S_k\psi_k.$$

Then optimal policy is exactly as in proposition 1, modulo changes in \bar{A} .

- *Proof:* Follows exactly as in proof of proposition 1.

Heterogeneity: “least-cost avoider principle”

► back

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- *Proof:* Follows exactly as in proof of proposition 1.

Interpretation 1: monetary “least-cost avoider principle”

Interpretation 2: “stabilizing the stickiest price”

Multiple shocks: general case

► back

Proposition 7: Consider an arbitrary set of productivity shocks to the baseline model, $\{A_1, \dots, A_S\}$.

- Conditional on sectors $\Omega \subseteq \{1, \dots, S\}$ adjusting, optimal policy is given by setting $M = M_\Omega^* \equiv \frac{S-\omega}{\sum_{i \notin \Omega} \frac{1}{A_i}}$, where $\omega \equiv |\Omega|$.
- The optimal set of sectors that should adjust, Ω^* , is given by comparing welfare under the various possibilities for Ω , using W_Ω^* defined in the paper.
- Nominal wage targeting is exactly optimal if the set of sectors which should not adjust are unshocked: $A_i = 1 \quad \forall i \notin \Omega^*$.

Price adjustment frequency tracks inflation

► back

Calvo/TDP models: frequency of price adjustment is exogenous to inflation

Menu cost models: frequency of price adjustment \uparrow if inflation \uparrow

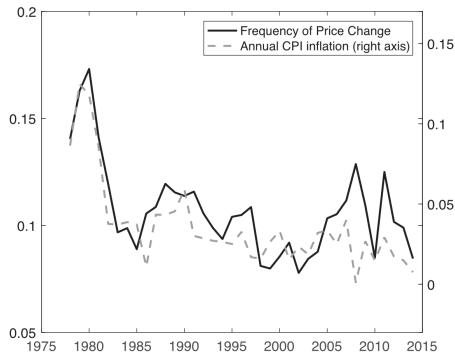


FIGURE XIV

Frequency of Price Change in U.S. Data

Figure: Nakamura et al (2018)

Price adjustment frequency tracks inflation

► back

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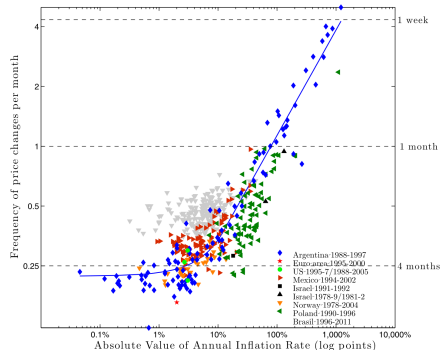


FIGURE VI

The Frequency of Price Changes (λ) and Expected Inflation: International Evidence

Figure: Alvarez et al (2018)

Price adjustment frequency tracks inflation

► back

Calvo/TDP models: frequency of price adjustment is exogenous to inflation

Menu cost models: frequency of price adjustment \uparrow if inflation \uparrow

(a) Frequency of Adjustment

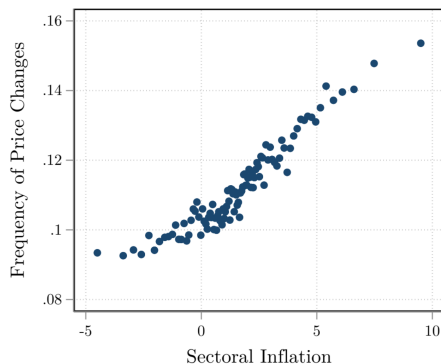


Figure: Blanco et al (2022)

Price adjustment frequency tracks inflation

► back

Calvo/TDP models: frequency of price adjustment is exogenous to inflation

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Figure 1: Frequency of price changes

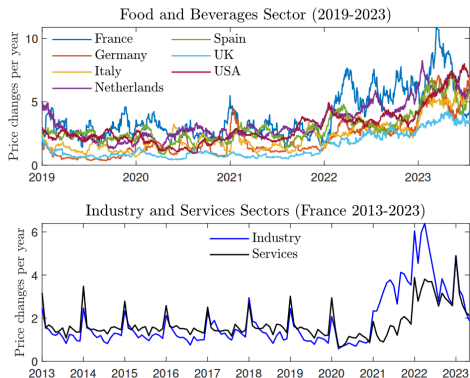
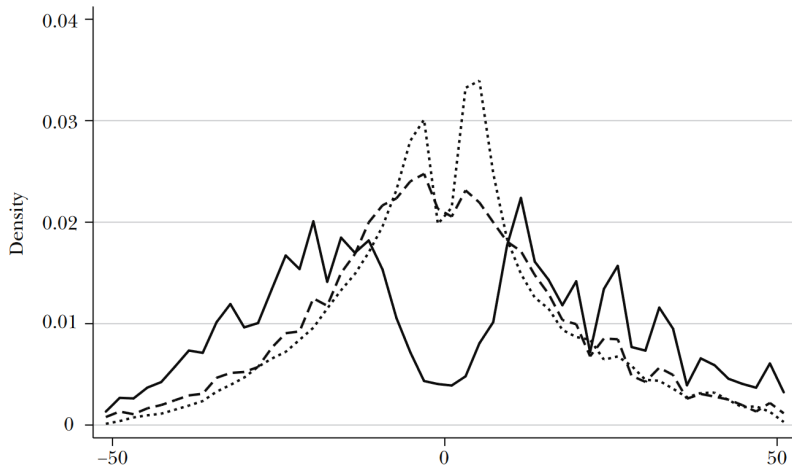


Figure: Cavallo et al (2023)

Evidence of inaction regions

Figure 8

The Distribution of the Size of Price Changes in the United States



The welfare loss of inflation targeting

► back

“Inflation targeting”: $P = P^{ss}$ (while having correct relative prices)

Proposition 2: Suppose $A_1 > \bar{A}$.

Then:

- Inflation targeting requires all sectors adjust their prices
- Welfare loss from inflation targeting \propto size of menu costs

$$\mathbb{W}^* - \mathbb{W}^{IT} = (S - 1)\psi$$

The welfare loss of inflation targeting

► back

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What are menu costs?

- **Physical adjustment costs.**
Baseline interpretation.

$$\mathbb{W}^* - \mathbb{W}^{IT} = (S - 1)\psi$$

The welfare loss of inflation targeting

► back

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Proposition 2: Suppose $A_1 > \bar{A}$.

Then:

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- Welfare loss from inflation targeting \propto size of menu costs

$$W^* - W^{IT} = (S - 1)\psi$$

What are menu costs?

- **Physical adjustment costs.** Baseline interpretation.
- **Information costs.** Fixed costs of information acquisition / processing.
 - * Results unchanged
- **Behavioral costs.** Consumer *distaste* for price changes.
 - * Results unchanged